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# THE USE OF BLAST FURNACE SLAG

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Preliminary Note – Prethodno priopćenje

The paper presents the results of experimental research that dealt with the substitution of finely ground blast furnace slag for Portland cement in the course of simple concrete manufacturing. Physical and mechanical properties of experimental concrete mixtures based on finely ground blast furnace slag were observed.

*Key words*: slag, blast furnace, Portland cement, concrete, physical and mechanical properties

**Korištenje troske iz visoke peći.** Rad predstavlja rezultate eksperimentalnog istraživanja koja se bave mogućnostima primjene finozrnate troske iz visoke peći za Portland cement u jednostavnoj proizvodnji betona. Promatrana su fizikalna i mehanička svojstva smjesa betona of finozrnate troske iz visoke peći.

*Ključne riječi*: troska, visoka peći, zamjena, Portland cement, beton, fizikalna i mehanička svojstva

## INTRODUCTION

It is known generally that industrial waste recycling and utilisation save fundamental raw materials and energy sources and, in addition, contribute to environmental protection.

A wide range of uses of recycled industrial waste is provided by the construction industry, where blast furnace slag and steel furnace slag are utilised as substitutes for natural aggregate most; nevertheless, e.g. finely ground blast furnace slag is commonly used in mixed cement production. At present, wastes from blast furnace and steel furnace production are, however, processed as secondary raw materials to a very limited extent. A large quantity of these valuable secondary raw materials are deposited outside plants and dumped. This situation is unsustainable from the ecological as well as economical point of view. Granulated blast furnace slag is one of the types of metallurgical slag. It is the case of a by-product of iron making. Major components include $SiO_2$, $Al_2O_3$, CaO; MgO, FeO and sulphides in the form of CaS, MnS and FeS are minor components. The reactions of activated blast furnace slag are analogous to those of Portland cement.

The use of finely ground granulated blast furnace slag as a substitute for cement is a standard practice from the technological, economical and ecological point of view. It improves the mechanical properties of concrete and its resistance to weak acids and salts [1, 2]. On a worldwide scale, attention is paid to research into mixtures of finely ground blast furnace slag and cement [3, 4]. The substitution of granulated blast furnace slag

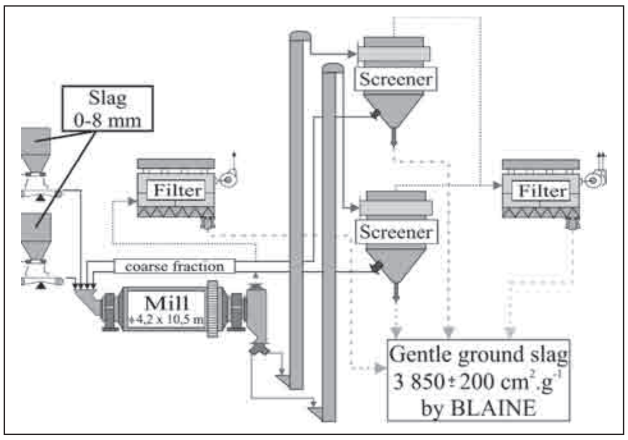


**Figure 1** Equipment flowsheet of a grinding plant for granulated blast furnace slag

for cement clinker usually leads to a decrease in primary strength and an increase in time of setting, which limits the use of a large portion of slag in slag Portland cement. To improve the reactivity of cement components [5 - 7], fine grinding and mechanical activation can be applied [8, 9].

For experimental research into the substitution of blast furnace slag for Portland cement, finely granulated blast furnace slag (MSJŠ) from the company Kotouč Štramberk, Ltd. was used. An equipment flowsheet of a grinding plant for granulated blast furnace slag is presented in Figure 1. The finer is the grinding of slag, the better are some properties, especially strength (primary, final), workability (plasticity) and bonding. The finely ground slag has a larger specific surface area and thus a larger water reaction surface area. Moreover, contact with fine additives and sand and gravel surfaces improves as well. For slag grinding, gravity grinding mills are utilised. The principle consists in material comminution by fall or impact and in powdering by grinding

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bodies. Gravity grinding mills are divided into ball, rod and autogenous mills.

## MATERIALS AND METHODS

### Blast furnace slag

Finely ground granulated blast furnace slag for experimental research was taken from the company Kotouč Štramberk, Ltd. Chemical analysis was made at the Nanotechnology Centre of VŠB – Technical University of Ostrava. On a sample of finely ground granulated slag (MSJŠ), the following analyses were carried out: determination of $SiO_2$, $SO_3$, CaO, $Al_2O_3$, MgO, $Fe_2O_3$, $K_2O$, and others as stated in Table 1.

Table 1 **Results of chemical analysis of slag MSJŠ**

| | Unit of measure | Result of determination |
|---|---|---|
| CaO | % | 36,3 |
| MgO | % | 11,7 |
| SiO2 | % | 42,5 |
| Al2O3 | % | 6,8 |
| Fe2O3 | % | 0,18 |
| SO3 | % | 1,56 |
| K2O | % | 0,36 |
| Cl | μg·g-1 | 156,6 |
| Sr | μg·g-1 | 377,3 |
| Ba | μg·g-1 | 834,7 |

The physical and mechanical properties of finely ground granulated slag are given in Table 2. The slag sample MSJŠ was subjected to a raster electron microscopic analysis. pyramidal particles of various sizes, which is caused by slag grinding. In a micrograph at 1000 x magnification (see Figure 2), slag is characterised by a high content of undisturbed.

### Aggregate

As aggregate for concrete based on finely ground blast furnace slag, aggregate of coarse fraction 8/16 mm from Dolní Benešov, gravel sand of fraction 4/8 mm from Dolní Benešov, aggregate of fine fraction 0/4 mm from Bohumín were used. Properties of the mentioned aggregate fractions are presented in Table 3.

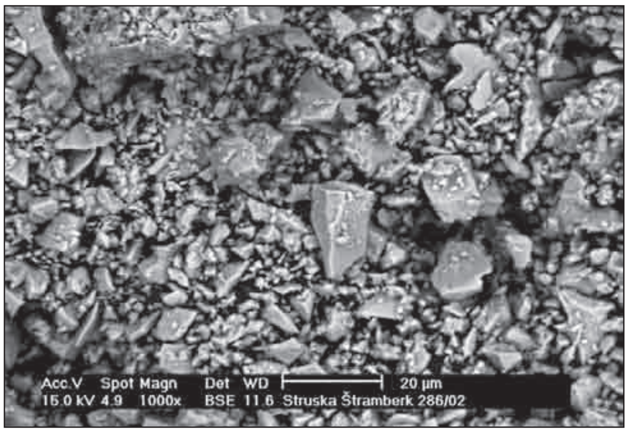


**Figure 2** Micrograph of slag MSJŠ (magnified 1000x)

Table 2 **Physical and mechanical properties of slag MSJŠ**

| Observed property | Unit | Values |
|---|---|---|
| Moisture | % | 0,15 |
| Absorption capacity | % | 21,26 |
| Fineness of grinding– sieve residue | | |
| - sieve 0,045 mm | % | |
| - sieve 0,063 mm | % | |
| - sieve 0,090 mm | % | 1,58 |
| Fineness - Blaine | $cm^2·g^{-1}$ | 3 852 |
| Bulk density | $kg·m^{-3}$ | 1 094 |

### Cement

As a fundamental binder and later as an activator for finely ground blast furnace slag, Portland cement CEM I 42,5 R from the locality of Hranice na Moravě was used. Observed properties of cement according to EN 197-1 [10] are stated in Table 4.

Table 3 **Properties of aggregate fractions**

| Property | Unit | Fraction 8/16/ mm | Fraction 4/8/ mm | Fraction 0/4/ mm |
|---|---|---|---|---|
| bulk density<br>- bulk state<br>- packed state | <br>$kg · m^{-3}$<br>$kg · m^{-3}$ | <br>1 410<br>1 670 | <br>1 610<br>1 890 | <br>1 690<br>1 720 |
| density | $kg · m^{-3}$ | 2 600 | 2 600 | 2 631 |
| wash-off particles | % by mass | 0,42 | 1,75 | 2,51 |

### Plasticisers

As a plasticiser for improving the workability of concrete based on Portland cement and finely ground blast furnace slag, a plasticiser designated "ADDIMENT plastifikátor BV1" was used.

Table 4 **Observed properties of cement**

| Observed parameter | Unit | Value | Required level accord. to ČSN EN 197-1 |
|---|---|---|---|
| 2 days compressive strength | $N·mm^{-2}$ | 32,1 | ≥ 20,0 |
| 28 days compressive strength | $N·mm^{-2}$ | 54,6 | ≥ 42,5<br>≤ 62,5 |
| 2 days bending tensile strength | $N·mm^{-2}$ | 6,36 | - |
| 28 days bending tensile strength | $N·mm^{-2}$ | 9,91 | - |
| Initial setting time | minutes | 130 | ≥ 60 |
| Soundness | mm | 1,0 | ≤ 10 |
| Specific gravity | $g·cm^{-3}$ | 3,07 | - |
| Specific surface | $cm^2·g^{-1}$ | 4182 | - |
| Sulphate content | % by mass | 2,84 | ≤ 4,00 |
| Loss on ignition | % by mass | 1,46 | ≤ 5,00 |
| Insoluble residue | % by mass | 0,44 | ≤ 5,00 |
| Chloride content | % by mass | 0,022 | ≤ 0,100 |

### Experimetal procedures

As far as the fundamental composition of test mixtures is concerned, the volume ratio of fine aggregate (fraction 0/4 mm) to coarse aggregate (fraction 4/8 mm, fraction 8/16 mm) was 40:20:20. Furthermore, the part of cement of class CEM I 42,5 R was substituted by slag MSJS in the amounts of 0, 10, 20, 30, 40, 50, 60, 80 and 100 % of cement mass. The consumption of cement of the comparative mixture was 320 kg/m$^3$.

## Consistency of Concrete Mixture

Figure 3 presents the values of slump of experimental mixes immediately after mixing and after 30 minutes. In this figure, one can see that using finely ground slag in rather small amounts, namely less than 20 % substitution for cement, the consistency of the concrete mixture grows. It is interesting that at 20 % substitution for cement it has been found that the consistency of the mix decreased in comparison with the mix 3 and corresponds to the mix 2/5. Then, at 30 % substitution of finely ground slag for cement, the workability of the mixture increases as well both at the determination of slump immediately after mixing and also after 30 minutes. At further increasing the substitution of slag for cement, the consistency of the mixes decreases immediately after mixing the concrete mixture as well as after 30 minutes. However, at 80 and 100 % substitution of finely ground slag for cement, the consistency grows rapidly immediately after mixing the concrete mixture (by minutes) as well as after 30 minutes.

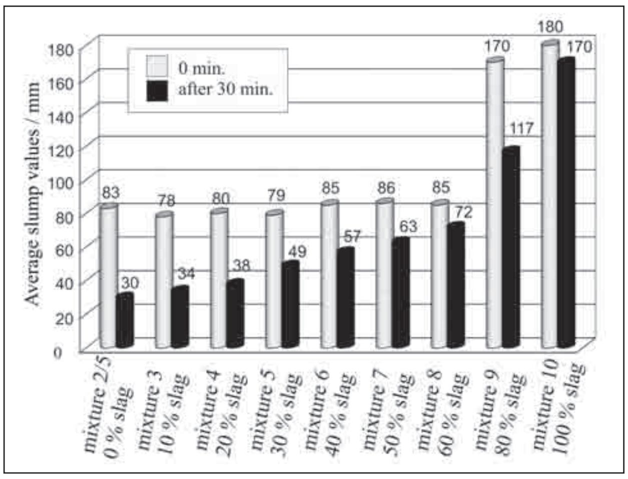


**Figure 3** Average slump values of experimental mixes

## Determination of cube strength

For carrying out the test, 18 pieces of cubes with a side length of 150 mm were manufactured for every mix, i.e. altogether 198 pcs of test specimens containing 0, 10, 20, 30, 40, 50, 60, 80 and 100 % of finely ground blast furnace slag. The determination of cube strength of all 9 mixes was carried out after 3, 7, 14, 21, 28 and 90 days.

In Figure 4 there are the results of determination of cube strength at selected combinations of substitution of finely ground slag for cement.

According to the results of measurement one can say that at higher rates of substitution of finely ground granulated slag for cement (60, 80, 100 %), a decrease in initial strength of experimental mixes in comparison with that of the comparative mix (mix 2/5) takes place. This phenomenon can be seen clearly in the case of mixes 8, 9, 10.

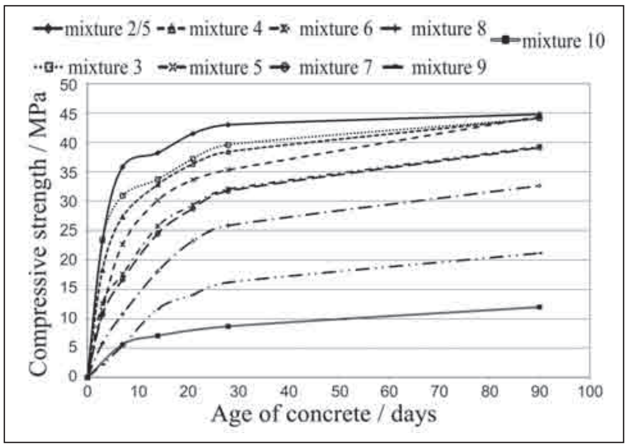


**Figure 4** Dependence of concrete strength on concrete age

From Figure 5 it is obvious that at an increased rate of substitution of finely ground slag for cement, the values of 28-day compressive strength of concrete decrease, namely from 43 MPa in the mix 2/5 (comparative mix) to 25,8 MPa in the mix 8 (per cent decrease in strength between the mix 2/5 and the mix 8 is 33,7 %) and even to 16,2 MPa (decrease by 62,4 %) in the mix 9.Nevertheless, values of 90-day strength are comparable with the strength of the mix 2/5 (comparative mix, 0 % of slag). The 90-day strength of the mix 5 is 44,4 MPa (in this mix we can see an increase in strength by 3,2 % in comparison with the 90-day strength of the mix 2/5).At an increase in the rate of substitution of slag for cement, a decrease in 90-day strength occurs in comparison with the comparative mix (mix 2/5) in the mix 6 to 39,3 MPa (decrease by 8,7 %) and in the mix 7 to 39,1 MPa (decrease by 9,1 %).

The higher is the rate of substitution of finely ground slag for cement, the higher are gains in compressive strength of concrete; they move in the range from $f_{c,cube90}$ to $f_{c,cube28}$. This phenomenon can be seen in the mixes 6,

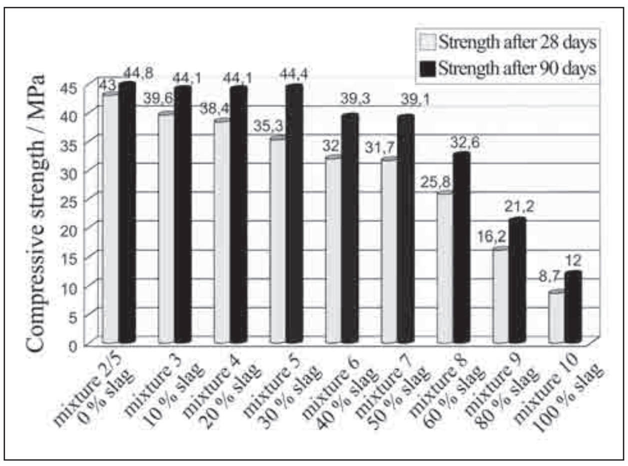


**Figure 5** Comparison of strength of concrete of individual mixes after 28 and 90 days

7, 8 in comparison with the comparative mix. At further increasing the rate of substitution of finely ground slag for cement, this gain diminishes.

## CONCLUSION

By research it has been proved that:

- at an increased rate of substitution for Portland cement above 20 % by mass, the consistency of concrete mixture grows;
- the strength of concrete based on finely ground granulated blast furnace slag in the amount of up to 60 per cent of content of Portland cement corresponds to structural concrete; moreover, it has been found that the plastic deformation of this concrete diminishes, which has also been confirmed by very brittle failure;
- the use of finely ground granulated blast furnace slag as a substitute for 100 per cent of cement for certain kinds of constructions (road and motorway base layers, construction of lay-bys, concrete encasement of concrete sewage pipes, backfilling of underground workings, stabilization and solidification of soils and rocks in the course of road and dam construction, and others) is from the point of view of concrete strength very real and from the economical point of view highly effective. Nonetheless, this statement should be supported by further experimental research into the physical and mechanical properties of concrete based on finely ground blast furnace slag.

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**Note:** The responsible for English language is Radmila Jelínková, Ostrava, Czech Republic